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EXPLOITING THE WEATHER GAP: METEOROLOGY AND NAVAL OPERATIONS IN THE 20TH CENTURY

A Thesis

Submitted to the Faculty

in partial fulfillment of the requirements for the

degree of

Master of Arts

in

Liberal Studies

by

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Abstract

Weather is an increasingly important factor in naval operations. Historical analysis provides examples of weather and its influence over military operations. Prior to World War II, weather conditions were simply endured by adversaries. In the 1950's and 1960's, the role of weather changed. This change in the military significance of weather has its roots in changing venues of naval operations, changes in forecasting technologies and changes in military weapons systems. During the 20th century, weather has made the transition from being an equalizer to a force multiplier. The United States need to continue its leading work in environmental prediction in order to maintain the "weather gap" between itself and its potential adversaries.

Preface

As a project, this paper required assistance from a multitude of people. I need to thank my Dartmouth College advisors, Professors Eric Posmentier, George Demko and Jere Daniell for their guidance and critical appraisals. Professor Joseph Zabransky from Plymouth State College also provided informal advice and comments on a variety of topics. My colleagues at the Holderness School, especially Peter Durnan, Chris Day, Jory Macomber, Wilson Everhart, and Mary Kietzman, supported my efforts by reading drafts and helping me to find what seemed like every source about the Navy and the weather. I also need to thank the members of the Naval Weather Association and the Public Affairs Officers at various military installations whose response to inquiries helped in the completion of this project. Finally, I must thank my wife Rachel, who provided immeasurable support for this project. This would not have been possible without her sense of humor, her support, and her love.

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Introduction

Regardless of geographical location, economic status, or political affiliation, the daily weather is a part of our life. Prior to leaving home, most people at least try to hear or see a weather forecast to help determine clothing or plan activities. And, "How's the weather there?" might be the universal conversational masterpiece. Although weather influences our lives, rarely does it significantly alter how we live our lives. Today, we have SUV's, insulated weatherproof garments, and innovative building materials as well as construction techniques that will get us through most of what nature throws our way. Although civilians easily adapt to weather conditions, military organizations must contend with the impact of meteorological factors. Military personnel, their equipment, and their operations are sensitive to a large number of environmental factors. In some cases, battles throughout history have been won or lost based on the weather.

Of the different branches of the armed services, navies have been the most susceptible to environmental conditions due to their operational environment. The different factors associated with operations in maritime environments have made weather forecasting especially important to naval operations. The US Navy, along with civilian help, has made significant investments in both personnel and equipment to ensure the timely preparation and dissemination of vital weather data.

The forecasts generated by the Naval Meteorology and Oceanography Command (METOC) have provided essential information to the men and women in the Navy for more than eighty years. Prior to METOC's contributions, the best source of information was usually the anecdotal experience of the ship's commander. On most occasions, weather was simply endured by the parties at conflict, with weather-induced victory or defeat largely dependent on location, or luck.

Weather plays a critical role in the conduct of naval operations. The role of weather has changed dramatically in the 20th century, making a transition from being an element simply endured, to a major factor dictating the conduct of battles. Specifically, the decades following World War II are the watershed era when this change took place. This new role of weather emerged not because weather has changed, but because of new naval strategies, advancements in weapons, and improvements in weather forecasting technology. In today's naval engagements, accurate depiction and forecasting of environmental conditions can be used to provide a significant advantage over an adversary.

Chapter One: Historical Cases Demonstrating the Significance of Weather and Meteorological Forecasts

Weather conditions have played a significant role in the history of civilization. Events on both land and sea have been at the mercy of meteorological conditions, and these have strongly influenced the foreign policy of nations, the conduct of revolutions, and the success or failure of military operations. As a factor, weather has not always been the single greatest factor in determining the outcome of conflicts. However, in some instances, weather has been truly decisive.

As important as the weather itself are the people who produced and disseminated weather information to decision-makers. With the improvement in forecasting abilities, weather personnel played an increasingly important role by assembling more accurate forecasts and enabling leaders to make more informed decisions. However, accurate information did not necessarily mean the forecasts were relied upon as significant factors worthy of consideration. In some instances, commanders who ignored forecasts encountered disastrous results.

Proprietor of perhaps the largest geographical empire in the thirteenth century, Ghengis Khan learned the important role of weather in military operations at sea. With his heart set on bringing the Japanese Islands under his control, Ghengis Khan attempted an amphibious assault in 1274. In keeping with the custom of ocean voyages during his century, Ghengis had astrologers and diviners on board his ships, the ancient

equivalents of modern meteorologists.[i] Available records do not detail if these weather personnel provide warnings of the disaster that beset the Mongol invasion fleet only a few days after their assault. Following the initial landings that favored the Mongols, a typhoon swept in from the Pacific and destroyed the Mongol ships at anchor, and forced a retreat back to China. Over three hundred ships and 20,000 men were lost.[ii]

Frustrated by the failure of his initial attempt, Ghengis effected another landing in 1281. This second invasion fleet consisted of forty-five hundred ships and 150,000 men. They set sail and initially retook the island of Iki and established a foothold on Kyushu. However, another typhoon struck and successfully repelled the invaders a second time. Over four thousand ships and 130,000 men were lost, most struck down on the beaches by bands of Japanese soldiers who killed the shipwrecked invaders.[iii] After these two experiences, the Japanese believed for many centuries that a powerful spirit guarded their islands. These divine winds were called *kamikaze.*

Another significant invasion thwarted by the weather was the Spanish Armada. Miscalculations on both the part of Philip II of Spain and Elizabeth I of England brought the two nations to arms in 1588. When amassing the largest single fleet in history, Philip II believed the capitulation of England to be a virtual guarantee. However, historians generally note Philip's overconfidence in the poorly trained soldiers and sailors that made up the bulk of his invading force.[iv] But neither this lack of talent nor the tactical superiority of the British would be the decisive factor of this engagement.

Throughout July of 1588, light winds and strong currents filled the English Channel. As a result, the British and Spanish ships engaged each other in small engagements that did not inflict serious damage on either side, with the exception of one battle where the Spanish lost two ships, the *Nuestra Senora del Rosario*, and the *San Salvador*. The Spanish fleet numbered at least one hundred forty ships, with nearly 21,000 soldiers embarked as an invasion force.[v]

When the English launched their fireship attack on the evening of 7 August, they had the weather gauge (they were windward of the Spanish fleet). Being windward or leeward (downwind) of an enemy force during the age of sail could be a tremendous advantage, or disadvantage depending on the situation. In the case of the English, being to windward was an advantage because of their use of fireships. A fireship was a vessel set afire and sailed towards an enemy fleet. As the Spanish retreated in disarray, the English closed in on their enemy for the first time in significant force. This was the opportunity to utilize their superior training and seamanship to defeat the mighty Armada.

Figure 1: Map of Spanish Armada Route[vi]



However, as the British gained on the Spanish fleet, the wind backed suddenly to the south, giving the Spanish the opportunity to sail away from the British.[vii] Instead of facing the British, the Spanish sailed counterclockwise around the British Isles and then onto Lisbon via the west coast of Ireland.

Although the ships of the English and Spanish fleets did meet and exchange gunfire, the meteorological conditions played a significant role in the outcome of the

engagement. First, the light winds and strong currents relegated the two sides to many skirmishes rather than one large engagement. And finally, as the English prepared to deliver a coup de grace, the change in wind direction allowed the Spanish to escape. Not only was an invasion of England thwarted, but the Spanish would never significantly threaten the British for supremacy of the seas.

Like sea battles, land engagements have also been affected by weather conditions. During the second half of the seventeenth century, France and England sought to gain control of the Dutch Republic. Although a relatively small country, the Dutch Republic functioned as the financial center of a world swelled with wealth from the Age of Exploration. The capital and resources of this unprecedented growth in European wealth congregated in the banking houses of Amsterdam. One of the problems of success was the threat of invasion by a hostile power. With England to the north of vital Dutch trade routes, and France to the south, it was only a matter of time before these two powers attempted to pillage the wealth amassed by the Dutch. England's attempts were exclusively naval, coming at significant cost to King Charles II. Over time, the expenditures needed to engage the Dutch became too much for Britain's shallow pockets, and the English monarch decided to curtail his attacks.[viii]

However, French King Louis XIV continued to apply pressure to the Dutch, and struck with an invasion force in the summer of 1672. French troops advanced along

both banks of the Maas River, circumvented key Dutch defensive positions, and threatened the Zuider Zee (a shallow inland sea to the east and south of Amsterdam.)[ix]

The Dutch defenders were badly outgunned and outmanned, and resorted to flooding the approaches to Amsterdam by destroying dikes. This created a 20 km moat around the city and temporarily saved Amsterdam from invasion. The French decided to wait until the water froze during the winter months before attempting an assault on the city. In late December, the French began to cross the flooded areas, but warmer than normal temperatures weakened the ice, and the French were forced to retreat. Temperature estimates for this time period in 1672 were nearly 3.5˚C, which was well above the average of 0.5˚C.[x] The unseasonably warm weather saved the Dutch, and spelled disaster for the French.

Over 100 years later, weather would have more disastrous consequences for the French nobility. In the summer of 1788, a severe drought struck France which impacted that year's harvest. Every weather observation station in France, with the exception of Paris, recorded precipitation levels that were lower than the average by at least 35%.[xi] This low level of moisture in combination with higher than normal temperatures resulted in a grain harvest that was only half of the mean figures for that period.[xii]

Many historians lend significant weight to the rise in grain and bread prices as the precipitating event that led to the French Revolution. Prices were at an all-time high just before the 14 July attack on the Bastille. According to some sources, prices were

75% higher compared to the previous year.[xiii] With more than 55% of peasant income dedicated to the purchase of bread, this increase in price was unbearable for the poor of France.[xiv]

Only a decade after revolutionary events in France, Britain also found itself at the mercy of meteorological conditions. In fact , "the climate governed Britain's naval strategy and planning for the Baltic region."[xv] Faced with crop failures in 1799 due to a cool and rainy growing season, Britain netted only one-half of its normal grain harvest.[xvi] Another disastrous harvest in 1800 put Britain on its heels again, having to contend with only a three-quarters harvest due to incessant rains in the latter part of August.[xvii]

Loss of the grain harvest for two successive years put Britain in a difficult position. Normally known as a grain exporter, Britain needed to shore up its reserves, and it turned to the ports that lined the Baltic Sea as a source of supply. However, all of these ports were under the nominal control of the Russian Tsar. Russia did not look favorably upon England for their support of Austria's campaign of territorial aggrandizement. Relations came to a crisis when Britain and Russia disputed ownership of Malta, which had originally been part of Napoleon's empire. In 1800, Tsar Paul I placed an embargo on British ships in all ports controlled or influenced by Russia, which effectively cut Britain off from restocking its grain supplies. This put

Britain in a difficult position, and the Admiralty sent a fleet to the Baltic to break the embargo.[xviii]

The British use of force to break the embargo and the preceeding examples underscore the broad impact of weather. As the nineteenth century drew to a close, technology began to provide the tools needed to understand the forces of meteorological phenomenon. For example, the invention of the telegraph made meteorology a practical science. Observations from distant points could be collected and analyzed, and then disseminated in relatively quick fashion. Scientists now had some of the tools they needed to begin making sense of the weather and the forces at work.[xix] This technological progression continued into the twentieth century, picking up considerable pace during the 1930's and 1940's. These specific developments will be considered in a later chapter. The net result of the technological change was increased accuracy and greater understanding of weather phenomenon.

With this increased accuracy, the role of the weather forecaster became more significant. During World War II, weather personnel redefined their role within the military command structure by providing key information to commanders. Weather still played its major role in the outcome of events, but now it could be used to the advantage of the military powers who could produce more reliable predictions of future meteorological conditions.

Weather forecasting and weather conditions played an extremely significant role in World War II. One of the best examples involves Operation Overlord (D-Day), when Eisenhower decided to delay the invasion on 4 June by twenty-four hours after input from the SHAEF (Supreme Headquarters Allied Expeditionary Force) Meteorological Committee led by Captain J. M. Stagg[xx] The forecast called for high winds and heavy precipitation, and would have put the invading force at a significant disadvantage. However, early the next morning Stagg announced a possible opening in the storm for approximately thirty-six hours on the following day. Based on this analysis, Eisenhower gave the order to proceed even though his advisors were still split on the go/no-go decision.[xxi]

The weather was also on the mind of the German defenders. Many historians have asserted that the Germans did not have adequate resources to forecast the conditions in the Channel during the first week of June.[xxii] However, a German meteorologist, Werner Schwerdtfeger, published in his memoirs in 1986 that the forecasts given to German commanders throughout the chain of command accurately predicted the conditions in the Channel.[xxiii] It is true that Field Marshall Rommel left his command post to see his wife for the evening, but that decision seemed to be based more on his personal interpretation of the weather than an official forecast. As he departed his command post in light drizzle, he remarked "There's not going to be an

invasion. And if there is, they won't get off the beaches."[xxiv] As a result of his own decision, he was not at his post when Allied forces landed.[xxv]

In the months after the Normandy landings, the Germans started to put more faith in their weather personnel. In early December 1944, a strange order came from the *Wolfsschanze*[*] requesting an almost impossible task. The German command staff needed to have a "two plus five day" forecast which means two days notice before a five day period of a certain condition. The Germans were looking for fog and snow over the Ardennes Forest region and southern England. Faced with this task, the German meteorology staff managed to deliver a forecast on 15 December which guaranteed only three days of fog in the region. Based on this input, the Germans launched their last ditch offensive known as the Battle of the Bulge (fought in the Ardennes forest during Christmas 1944) .[xxvi] Without the benefit of air cover and their forward positions overextended, the Allied troops struggled to maintain their lines in the face of intensive German attacks. However, the return of clear weather enabled Allied air power to support the ground troops, and the Germans eventually retreated. The German thrust came dangerously close to breaking the Allied offensive.

Like the Army, the Navy in World War II wrestled with key decisions revolving around the forecasts of Navy meteorologists, and in more than one instance, weather

[*] Wolf's Den-Hitler's secret bunker

and weather forecasting played significant roles. An example of the significance of weather and METOC personnel is during the Battle of the Coral Sea.

In May 1942, the Japanese continued their march southward across the Pacific, threatening Australia. Admiral Nimitz, the Commander-in-Chief of the Pacific Fleet, deployed the U.S.S. Yorktown and the U.S.S. Lexington to the Coral Sea in order to check the Japanese advance. The weather in the region of battle was dominated by a stationary front that produced clouds in the lower and middle layers. This provided good cover for both the Japanese and American carriers, making both difficult to detect. With the weather starting to clear on 7 May, the Americans decided to alter course and hide inside this front to prevent his force from being discovered. This strategy paid off. On 8 May 1942, the American pilots broke out of the clouds only miles from their targets, and caught the Japanese fleet by surprise. Under the recommendations of their METOC officer, Lt. Cmdr. Hubert Strange, the pilots of the *Lexington* flew under the cloud bases all the way to their target, and succeeded in sinking the first major Japanese warship of World War II. The pilots of the *Yorktown* did not get this guideline from their METOC officer, and did not hit their intended target. [xxvii]

The same weather strategy that helped the Americans also aided the Japanese. In a later stage of the battle, the American carriers sailed southeast, leaving the frontal zone and entering the region of clear skies. This enabled Japanese pilots to attack the U.S. ships in perfect visibility and sink the U.S.S. Lexington.

The Battle of the Coral Sea remains one of the most significant battles in history for two reasons. Most history students learn that Coral Sea was the first time that major naval fleets engaged each other exclusively with their aircraft. Not a single shot from a naval gun was fired at another ship. However, the meaning of the words "weather gauge" had also become redefined. If you had the weather gauge in the days of sailing vessels, you were upwind of your enemy and able to maneuver more adeptly. In the age of the carrier, the weather gauge now referred to being assisted by the weather.[xxviii]

Similar to the Battle of the Coral Sea, the Battle of Midway in early June 1942 is also a good example of meteorological impacts on naval operations. Poor visibility and fog masked the approach of the Japanese strike fleet to the American scout planes who knew the course and general location of the attacking force, but were unable to locate it until it was only 180 miles from Midway.[xxix] This prevented the American commanders (Nimitz and Fletcher) from ordering strikes until they themselves were in range of the Japanese carriers. The Japanese force had been steaming in the intensifying storm system that had been predicted accurately by Pearl Harbor's weather station. However, the storm system was moving faster than the task force, and eventually, the Japanese fleet steamed in almost unrestricted visibility.[xxx] This made them vulnerable to attack from U.S. Navy forces.

When US Navy forces attacked the Japanese, they utilized recommendations from their METOC officer, Lt. Cmdr. Strange. Strange recommended that his pilots

watch for wind shifts associated with the front by observing the change in the direction of the white caps. This allowed them to identify the change in wind, and compensate for the direction change in their flying formation. As a result of Strange's recommendations, the planes from the U.S.S. Yorktown were very tight compared to the other carrier groups as they approached the Japanese carrier forces.[xxxi] This enabled them to mount a more effective attack on the Japanese carriers. In this battle, the Japanese suffered the loss of four carriers to the one lost by the Americans. More importantly, the Japanese lost a large portion of their best trained carrier pilots, and it is believed that the Japanese never regained the high level of training and expertise in their naval aviators after this engagement.[xxxii]

The ability of METOC personnel to predict the weather assisted naval commanders in their conduct of operations. However, forecasts were not always sufficiently accurate, nor did commanders always follow the recommendations of weather personnel. In some instances, the decision to ignore METOC recommendations had disastrous impacts on naval operations. One striking example occurred in mid-December 1944.

In order to support the land operations in the Philippines, Admiral Chester Nimitz directed Admiral William Halsey and his task force to operate in the waters just east of Luzon in order to provide air cover to General MacArthur's land forces. On 10

December, Halsey's forces sortied from Ulithi with 131 ships, including twelve carriers to assist MacArthur.[xxxiii]

In order to sustain operations, Halsey positioned his replenishment ships (oilers and ammunition ships) approximately twenty-four hours sailing time due east. This left his supplies close enough for quick access, but also out of range of Japanese bombers. Halsey's carriers dashed out ahead, delivered air strikes for three days, and then returned to his replenishment ships on 16 December.

Weather indicators on 16 December were vastly different among ships, depending on location.[xxxiv] However, the barometers dropped significantly on all the vessels, and the Third Fleet soon found itself in the grips of Typhoon Cobra. As the Fleet passed through Cobra, three Navy ships were lost with 790 officers and men, and nearly 100 aircraft.[xxxv]

With such an appalling loss, Admiral Nimitz convened a board of inquiry to investigate the events surrounding Cobra. Perspectives on what happened vary considerably. Admiral Halsey maintained that METOC did not give him suitable information with which to make an informed decision. According to Halsey, there were limitations in the data provided from Fleet Weather Central in Pearl Harbor, and reconnaissance information was too slow in being decoded[xxxvi] However, other sources (Halsey's METOC officer) indicate that Halsey received the forecasts warning of a major typhoon, but was too preoccupied with refueling/replenishment to avoid

Cobra.[xxxvii] Were these the actions of an uninformed commander, or the moves of an aggressive admiral pursuing the enemy?

Although this question was supposedly answered in a court of inquiry that validated the former explanation, the latter approach of an aggressive admiral may be more fitting. Although either explanation is possible, Halsey ran straight through another storm only seven months later in June 1945. Although the losses were less than Cobra, Typhoon Viper managed to exact a significant toll on the U.S. Navy. Thirty-three ships were damaged, seventy six planes were destroyed, and six men were killed. In fact, Halsey suffered more losses at the hands of Typhoons Cobra and Viper than by the actions of the Japanese.

Clearly, METOC officers and their products had significant impacts on the course of naval operations during World War II. And, in the instances where their forecasts were ignored, disaster struck. The Battle of the Coral Sea, the Battle of Midway, and Halsey's Typhoon fiasco all underscore the pivotal role of the naval meteorological officer. This would prove to be true in Korea as well.

Meteorology in Korea reversed the roles of the American and Germans in World War II. In the European theatre, German meteorologists were at a disadvantage because the general flow of the weather was from west to east. While the Allied forecasters had ample data on which to rely, German meteorologists had to struggle with much sparser information. This is the situation METOC personnel were faced

with in Korea. Most of the Korean peninsula's weather is dependent on the Asian continental land-mass. While the Russian meteorological observations were either broadcast in the clear, decoded, or useless[xxxviii], the observations from Communist China were unavailable to the Americans.[xxxix] This put them at a disadvantage in generating forecasts for the Korean area because they did not have accurate information about the weather patterns upwind of their forecast area. This meant that the enemy would likely have more accurate weather information. Although American forecasters were at a disadvantage for patterns emerging off of the Asian continent, they were at an advantage for predicting the typhoons which are maritime in origin. It was this situation that allowed Navy meteorology to be effective.

At the outbreak of the war, there were no navy meteorological assets in the region with the exception of ship-based personnel. Unlike the Air-Force that had a weather central in Tokyo, the Navy had been caught unprepared.[xl] Vice-Adm. Arthur Struble, in command of the Seventh Fleet, had only a chief-aerographer's mate (CAM) and one areographer's mate (AM) onboard his flagship, the U.S.S. Rochester.[xli] To make things more difficult, weather observations and forecasts by radio from the USAF weather central in Tokyo and other information sources were not consistently available (out of radio range) to Joseph Zaffino, Struble's CAM.[xlii]

In the early days of the conflict, the forces defending South Korea had been pushed back to the Pusan Perimeter located in the southeastern portion of the

peninsula. In order to ease the pressure on the defending forces, the Navy had been conducting strike missions trying to cut off the lines of supply to the advancing North Korean forces. On 21 July 1950, Zaffino presented an opportunity to Struble that would enable the Navy to strike North Korean assets with surprise.[xliii]

A typhoon had been making its way towards the Korean Peninsula, which would force the Seventh Fleet to make a course change. Zaffino informed Struble that he could make one of two choices. A conservative plan would be to head northeast of the Japanese island of Honshu, which would help shield the fleet from the major effects of the typhoon. Zaffino's other option was to make a fast night passage into the Yellow Sea and seek the protection of the island of Saishu To. This option would allow the U.S.S. Valley Forge to launch operations in defense of the Pusan Perimeter. However, this plan would work only if the typhoon turned more to the northwest, something that Zaffino felt it would do.[xliv] Struble went with Zaffino's forecast, and it held. As a result of Zaffino's reliable forecast, Struble launched air strikes that helped destroy an ammunition train as well as several key bridges. As a result of his efforts, Zaffino was awarded a bronze star by Secretary of the Navy, Dan A. Kimball.[xlv]

Another major navy meteorological effort centered around the daring Inchon landings. In order to relieve pressure on the fragile Pusan Perimeter, MacArthur proposed landing amphibious forces (Operation Chromite) on the western coast of Korea at Inchon, which would cut off the supply routes of the encroaching communist

forces. Inchon presented a difficult meteorological and oceanographic situation. The tidal range at Inchon was thirty-two feet, which limited day-time landings to only three or four days each month. [xlvi] Furthermore, the Japanese tide tables for Inchon disagreed with the ones compiled by the U.S. Navy.[xlvii]

In order to resolve this issue, the navy dispatched Lt. Eugene Clark to assess the area around Inchon prior to the landings. On 1 September 1950, Lt. Clark and his team of ROK officers (who had been Japanese Navy Officers in WWII) landed and performed a thorough reconnaissance of the area. Their reports confirmed that the Japanese tide tables were more accurate, that the mud-flats would support no significant weight, and that the sea walls surrounding the invasion beaches were much higher than estimated.[xlviii] This data was absolutely key in preparation for Operation Chromite.

After the planning had been completed, the weather situation became important with Typhoon Keiza entering the area. Navy and Air Force meteorologists based on Guam forecasted that Keiza may interfere significantly with the Inchon landings.[xlix] Under this forecast, the critical supply ships changed course to seek protection from the storm. However, an experienced aerologist, Lt. Cmdr. Charles Barron felt that only the edges of Keiza would impact the supply fleet. He recommended to Admiral Robert Doyle that the supply fleet reverse course again and keep the Inchon landings on schedule. His forecast proved to be correct and the landings occurred on the established timetable. [l]

Yet, another example of the significance of personnel in the decision-making process in regard to meteorology. Similar to experiences in World War II, Navy METOC personnel played a significant role in the conduct of naval operations in the Korean War.

Clearly, weather conditions have had a significant impact on civilization. Countries have been saved from invasion (Japan, Britain, Netherlands), changes in foreign policy have been made (Britain, Germany), revolutions have started (France), and battles have been won and lost (Germany, Allied Forces, North Koreans) on account of meteorological conditions. In some cases forecasts were ignored (Germany, United States) and disastrous results occurred. The historical record demonstrates the vital nature of weather prediction and personnel.

The role of weather prediction and METOC personnel gained even greater significance after the end of the Korean conflict. During the twentieth century, METOC continually adjusted in order to meet the demands required by the Navy. These demands shifted significantly in response to two factors. First, the strategy followed by the Navy adjusted to the changing nature of the adversaries faced by the United States. This required changes in overall naval strategy, which necessitated major shifts in the types of information required by naval commanders. And second, advances in naval ordnance brought new demands on METOC staff to provide more accurate

information. These changes made weather, and weather forecasting more critical to naval operations.

Chapter Two: Recent Changes in US Naval Strategy and Weapons Technology

Since the end of World War II, the United States Navy has faced numerous threats around the world. In order to deal with those challenges, policy makers have followed a defined strategy maximizing the strengths of the Navy and achieving the goals of civilian policy makers. From the Soviet Union to Osama bin Laden, the variety of threats has created a variety of approaches to naval operations, ranging from open ocean conflict to close-in shore combat. In addition to recent changes in strategy, innovations in weapons technology in the last forty years have altered the conduct of naval operations.

In order to keep pace with the changes in these two areas, METOC staff altered the support they provide to naval personnel. Weather has always been important to ships at sea, but its role has changed significantly in light of current naval strategy and weapons technology. Prior to World War II, the weather forecast came largely from the experience of the ship's commanding officer who provided anecdotal forecasting based on his experience. In the post World War II-era, naval operations reached a level of sophistication requiring a more comprehensive suite of products to support operations. As new strategies and weapons evolved, the role of the weather forecaster has grown significantly, and consequently, navy meteorologists fulfill a mission-critical role to current and future naval operations.

The pillars of American maritime strategy rest on two works released close to the turn of the twentieth century. Alfred Thayer Mahan's The Influence of Sea Power on History (1880) and Julian Corbett's Some Principles of Maritime Strategy (1911) provided a framework for creating a plan to counter the adversaries faced by maritime forces. Prior to these works, naval officers had very little concept of tactics and no overall strategy. The approach that naval officers used could be summed up in the words of British Lord Dundonald: "Never mind manoeuvre, always go at them." The concept of war at sea being a political act that should be connected to some overall national direction was totally foreign.[li]

In the United States, this view changed when Captain Alfred Thayer Mahan joined the faculty at the Naval War College in Newport, RI. The son of a West Point professor, Mahan entered the Naval Academy against the advice of his father. After completing his course of study in 1859 and an undistinguished career as an officer for the Union in the Civil War, he was invited by Commodore Stephen Luce to join the faculty of the newly formed Naval War College in Newport, RI. Mahan immediately accepted, and embraced the opportunity to pursue his academic interests. He arrived in Newport in 1886, but found his role changed from professor to President of the College because Luce had been ordered back to sea.[lii]

Mahan's basic message to the officers in the program focused on the need for the United States to embrace the role of an international power and understand that naval

power, in addition to land power, held the key to the success of the nation. In order to make this change, Mahan relied upon the lessons of history to teach about the future. "The study of the sea history of the past will be found instructive, by its illustration of the general principles of maritime war."[liii]

In history, Mahan found the lessons applicable to maritime strategy. Drawing upon the experiences of various maritime powers between 1660-1783 and the writings of the great Swiss strategist Antoine-Henri Jomini, Mahan argued for three cornerstones in an overall naval strategy. First, concentration of forces allowed a power to overwhelm an adversary. Second, geographical position and a direction of attack to neutralize an enemy's response were crucial to success. Finally, a close relationship between logistical support and combat elements was essential for success.[liv]

Using these three elements, Mahan promulgated the idea of seapower, and the link between naval war and national policy. Possession of a strong navy allowed for lucrative commercial enterprises, and lucrative commercial enterprises funded strong navies. Mahan concluded that being a great power meant that you had to be a country with considerable seapower. And the relationship between battles at sea and the pursuit of a national end are inextricably linked.[lv]

In order to attain seapower, a fleet functioned as an offensive weapon. According to Mahan, it should be used wherever possible, "and War, once declared, must be waged offensively, aggressively. The enemy must not be fended off, but

smitten down."[lvi] And although fleet action could be decisive, a single cataclysmic battle would not necessarily defeat an enemy. A blockade could strangle an enemy by reducing its seapower to the point where weakness and lethargy force a capitulation.[lvii]

These fundamental concepts permeated the curriculum of the Naval War College, and had an immediate impact on national policy. Shortly after Mahan's arrival at the Naval War College, Congress authorized the construction of a group of ships known as the "ABCD Ships" (Atlanta, Boston, Chicago and Dolphin), and then six months later, authorized three more sea going battleships.[lviii] And, Mahan's influence extended beyond the realm of maritime and naval strategy. According to historians and contemporary critics, he was the most prominent author of his contemporary time who clearly proved the importance of historical analysis during a period of extraordinary technological change.[lix]

In addition to Mahan, Julian Corbett also produced a body of knowledge attempting to persuade readers that a systematic approach to seapower was essential to success. Unlike Mahan, Corbett had no practical experience as a naval officer. Born in England, he was educated as a lawyer, but retained an interest in maritime topics. He wrote some short articles on naval history which were published and caught the attention of the British Admiralty. This enabled him to lecture occasionally at the Royal Naval War College in Greenwich, England. After the publishing of his renown work,

Some Principles of Maritime Strategy, Corbett worked directly for the British Admiralty during World War I.

Similar to Mahan, Corbett reflected on the relationship between naval war and national policy. However, Corbett made a distinction between a government with a strong land-based power and a government with a strong sea-based power, effectively stating that one could be great without the other. This assertion directly challenged Mahan, a contemporary of Corbett's. Corbett noted that an enemy might be able to stay out of range, and therefore could not be destroyed. This meant that concentration was not a golden rule in naval warfare. Also, since a fleet might not be able to be destroyed, the real target should be the sea commerce of the nation. If you destroy the ability to procure wealth, the enemy will captitulate.[lx]

Both Mahan and Corbett knew each other, and both men were influenced by the writings of the other. They shared many similarities and some fundamental differences. As historians, they differed in their approaches and methods. While Mahan's assertions found their support from secondary sources, Corbett's ideas were deductions from primary sources.[lxi] With these two men forming the base of subsequent maritime strategies, maritime nations tried to develop approaches to controlling the world's oceans for their benefit. The United States used these two thinkers as a foundation for its naval strategy.

Historically, the naval strategy of the United States Navy falls into several different categories. These different strategies can be attributed to respective contemporary political and technological environments. The "continental" phase existed from 1776 until the 1890's when the US Navy maintained a relatively weak presence on the world's oceans. Then, the acquisition of American overseas colonies and burgeoning technological advances heralded the "oceanic" phase when politicians and military commanders embraced the Mahanian and Corbettian ideals of seapower. This oceanic period includes the period through World War II when the United States became the undisputed champion of the world's oceans. The post-1945 world saw the end of this phase, and the introduction of the "transoceanic" period.[lxii]

The transoceanic period adequately describes the current strategic posture of the American Navy. Like its predecessors, the transoceanic period metamorphosed in response to changing political and technological circumstances. However, two distinct periods straddle the transoceanic period. Between 1945 and 1990, a focus on "blue-water" (i.e. open ocean) operations characterized the deployment of forces. After 1990, the in-shore or littoral environment dominated the thinking of naval commanders.

The transoceanic blue-water period embraced a new focus on the job of the US Navy relative to World War II. Command of the sea was paramount, but the threat of a worthy adversary had vanished at the conclusion of the war. Only Great Britain and the Soviet Union posed any threat to the United States on the high seas, and most

believed it would be unlikely that Great Britain would attempt an aggressive war in the near future.[lxiii] With the Soviet Union as a likely adversary, naval planners focused on developing a new approach to naval strategy, an approach that would assume a conflict in open ocean environments.

This assumption of open ocean combat was a result of the geographical disposition of the two adversaries. The United States enjoyed significant water barriers (Atlantic and Pacific Oceans) that had to be crossed by potential adversaries. In order to defend the country, hostile forces would be intercepted long before they approached the coastlines of the country. The Soviet Union's geography also contributed to the idea of the blue water strategy. Although the coastline of the USSR was significant, the vast majority included areas difficult to navigate all twelve months of the year. Add these two geographical situations with the political climate of the post-World War II era, and a blue water strategy becomes the most likely strategic approach. And, the Soviet naval buildup only served to confirm the assumptions of the military planners.

Since the turn of the eighteenth century, Russians and their Soviet descendants sought to create and maintain a fleet of combatant ships. The success of European powers in maritime commerce motivated Peter the Great to prioritize a presence on world oceans. In the decades following World War II, the Soviet Union renewed this approach, launching a building campaign that created the largest navy in the world (based on number of ships.) It built more than 2,500 merchant ships and was second

only to Panama in terms of ships registered. Its fishing fleet placed second only to Japan, and its oceanographic research fleet dwarfed other fleets, attaining a size larger than the rest of the world combined. By all measurements in 1970, the Soviet Union attained the status of the most powerful sea power in the world.[lxiv]

This situation alarmed the United States. America had also constructed a massive fleet, but decades earlier. During World War II to meet the needs of a two-theater war, US shipyards turned out massive amounts of tonnage. After the Pacific fleet was nearly annihilated during the Pearl Harbor attack and the Atlantic merchant fleet suffered massive losses due to U-boat activity in the Atlantic, shipbuilders turned out large numbers of combatant and non-combatant ships. By early 1943, shipyards were launching 1.5 million tons more per month than the total lost to Axis forces. The majority of the new construction provided the base of the American navy in the three decades following the Second World War.[lxv]

In the middle to late twentieth century, the forces of the US Navy were arrayed against the formidable threat of the Soviet Navy. This was not an easy task. In the post World War II world, budgets for the US Navy followed the pattern evident in history: funding varied dramatically. Many conflicting requirements (deployments to Korea and Vietnam as well as modernization) nearly brought the navy to its knees in terms of readiness. At the conclusion of the Vietnam War, the US Navy was not in a good position to match the burgeoning Soviet blue-water forces. [lxvi]

Paradoxically, the struggle of the US Navy in the post World War II world can be attributed to its exemplary record during the war. The destruction of the Japanese Navy and the power of the atomic bomb had many members of Congress considering the elimination of a navy fleet altogether. Their reasoning centered on the fact that there was no enemy to fight, and that atomic bombs made large ships obsolete. Why should you pay for large carriers when you can have fleets of B-36 bombers equipped with nuclear weapons? In this environment, the Chief of Naval Operations (CNO) found himself fighting for the very survival of the navy.

In academic and intellectual circles, historians and strategists attempted to raise awareness of the growing Soviet threat. In 1954, Admiral Robert B. Carney noted in a speech to the Naval War College that "we cannot exclude that Russia will in time build carriers. The Russian Navy is the one Soviet service which is more heavily manned than in World War II."[lxvii] However, even though there was clear evidence that a navy was an important part of foreign policy and national defense, the navy was allowed to deteriorate during this period.

The value of the navy was obvious to some, especially after several world crises required quick response on the part of American military forces. In these cases, only the US Navy was prepared to respond quickly. One of the best examples involves the Korean War. Naval assets from carriers were the only forces able to provide support to the beleaguered forces defending South Korea, and the Seventh Fleet was the only thing

preventing Communist China from invading Taiwan. This changed the views ofsome supporters of the Air Force overnight.[lxviii] However, many viewpoints were not changed. The proponents of eliminating the Navy would need more convincing.

The convincing would come in the first part of the 1970's. The degradation of US naval assets became painfully apparent during the waning years of conflict in Southeast Asia. During the Vietnam War, the US Navy was forced to operate World War II-era ships for long periods of deployment. For example in January 1969, nearly sixty percent of US ships were more than twenty years old, while the figure for the Soviet Navy was less than one percent.[lxix] Morale and readiness reached new lows. With an outdated fleet, low morale, and dearth of funds, facing the Soviet Union in a maritime conflict looked bleak.

While American assets were allowed to decay in the 1950's and 1960's, the Soviet Union pursued a different path. In 1954, the USSR made plans to build a significant number of naval ships designed to operate beyond the coastal waters.[lxx] By the 1970's, it was clear that the Soviet Union would be the primary adversary, and that the theater of operations would most likely be in the open ocean environment. Adhering to the Mahanian principles, sea control appeared even more important as control of the sea lanes to Europe would be absolutely necessary to defend NATO forces against a possible Warsaw Pact attack. These "blue water" tactics dictated that US Navy units

would operate far from land, and they would need every available tool to provide an advantage against their Soviet counterparts.

In the 1970's and 1980's, the US Navy focused on this blue water threat of the Soviet Union. This approach appeared in a publication entitled "The Maritime Strategy", a classified document from the Vice Chief of Naval Operations Admiral William Small, and distributed throughout the US Navy in 1984.[lxxi] "The Maritime Strategy" was presented as a series of stages in dealing with the Soviet Union. The example presented to Congress utilized an invasion of Norway as a test case. During Phase I, a deterrent phase, NATO and US Navy assets would deploy quickly to the region and encourage the Soviets not to further the war. Phase II involved striking back, that "the best defense is a good offense", and the forward deployment of submarines and surface-vessels. The final phase would be to bring the war to the enemy's homeland and bring terms favorable to the United States and NATO.[lxxii]

This strategy required substantial naval assets, and the leadership of Secretary of the Navy John Lehman secured considerable support from Congress and President Ronald Reagan. The 1980's was a period of US naval growth, and the realization of a 600 ship fleet. Fiscal expenditures for the Navy in 1983 were $82 billion dollars compared to $108 billion dollars in 1989.[lxxiii] But, these expenditures and the strategy they supported would drastically change in the 1990's.

On Christmas Day 1991, Mikhail Gorbachev resigned as the leader of the USSR, and turned his responsibilities over to Boris Yeltsin, the president of Russia. This marked not only the end of the political entity, but the end of the military entity as well. As the break up of the Soviet Union progressed, military assets were distributed among the various nations and the once formidable navy that faced the US Navy no longer existed. This required a massive change in strategic outlook for American forces, and this change manifested itself in a posture statement entitled "From the Sea"

"From the Sea" first appeared in the Navy News Service on September 30, 1992. This statement of strategy departed significantly from the prevailing approach in the 1980's. Taking into account the changes in world politics, this strategy focused on dealing with several regional conflicts rather than a global war between two superpowers. "This strategic direction, derived from the National Security Strategy, represents a fundamental shift away from open-ocean warfighting on the sea toward joint operation conducted from the sea." The Navy needs "to concentrate more on capabilities required in the complex operating environment of the 'littoral' or coastlines of the earth."[lxxiv]

The change in strategy from blue water to littoral operations shifted the focus of METOC. Instead of providing forecasts covering large open ocean areas, the more complex littoral regions would need to be examined in detail. This fundamental change has encouraged new approaches to forecasting and to forecasters.

The shift from open ocean environment to littoral areas is significant from several different perspectives. In the open ocean environment, the meteorological and oceanographic variables are relatively simple compared to the variables of the littoral zone. Air and water masses in the blue water environment tend toward uniformity. The variables at work in that environment differ greatly from those present in the littoral environment due to the proximity of land.

In the open ocean regions, the sun's radiation heats the water at a rate that is partially dependent on the characteristics of the water mass. However, in the littoral environment, land and water are in close proximity. Land and water absorb radiation from the sun at different rates which creates a much more complex environmental forecasting environment.[lxxv]

For example, unlike the open ocean, topography significantly influences local conditions. Specific terrain features can generate thunderstorms and other phenomena such as lenticular clouds and standing mountain waves. The temperature difference between the ocean and land create offshore and onshore winds depending on the time of day. Beach profiles change according to the season, and currents are significantly affected by underwater topography. Density differences between fresh and salt water create a complicated environment where different temperatures and salinity levels drastically alter the characteristics of the water column.[lxxvi] All of the factors described above can impact the deployment of vehicles, personnel, and weapons systems.

Due to this change from blue water to littoral operations, METOC needed to adjust its operations. New forecasting products, new technologies and new training practices characterize the latter part of the 1990's at METOC. Although these changes are significant, adaptation to new challenges is an old theme in the Navy. The METOC community has been able to adapt to every challenge faced, and they have faced similar challenges like the change to littoral environments.

At the outbreak of World War II hostilities on 1 September 1939, METOC leadership in the Navy consisted of Lt. Commander Wilbert "Red" Lockhart with a staff of only three support personnel.[lxxvii] Lockhart had become known as the Navy's most capable meteorologist in a short period of time. Throughout several duty rotations, Lockhart had won the confidence of his superiors, right up to the Commander in Chief of the U.S. Fleet by presenting meteorological reports that were utilized with great success in the field. Examples include the use of upper-level wind reports to direct gunfire from battleships, and the forecasting of Santa Ana winds in the conduct of fleet battle exercises.[lxxviii]

The major problem facing Lockhart revolved around the distribution of data to navy stations and ships in a wartime situation where fleet protocols specified radio silence. Lockhart put together a task force to solve the problem, and the solution developed created a central information center where data would be collected and products would be issued. This concept of the "weather central" was put to use

immediately, and the navy established two weather centrals, one for the Atlantic based in Washington, and the other for the Pacific based in San Francisco.[lxxix]

As the organization began to take shape, the next key requirement involved staffing the mushrooming meteorological requirements of the Navy. Requirements dictated 1,800 additional naval meteorology officers, and these college-educated candidates were recruited, commissioned, and sent to one of five universities for a crash course in graduate-level meteorology.[lxxx] These five universities (University of Chicago, UCLA, CA Institute of Technology, MIT, NYU) as well as the Army Air Force Tactical Training Command (TTC) at Grand Rapids, MI were responsible for training all the meteorological officers for the Navy and the Army Air Force.[lxxxi]

When the Navy began to recruit qualified officers, it realized that there was a major shortfall for meteorology positions. In order to meet demand, the Navy tapped a new pool of previously unconsidered candidates: women. Encouraged by the following communication from the Department of Commerce, the Navy's WAVES (Women Accepted for Voluntary Emergency Service) program expanded to include meteorological officers.

> It is apparent that increasing difficulty will be experienced in securing qualified persons to fill many of the positions essential to the prosecution of the National Defense Program. As one means of meeting this situation, appointment officers who have been in the habit of requesting the certification of male eligibles [sic] only for certain positions are urged to explore the possibilities of employing women….Surveys have demonstrated that women can satisfactorily perform almost all kinds of work that men can perform.[lxxxii]

Although only approximately 100 women were ever trained for meteorological positions, their placement at stateside locations allowed the WAVES to free up men for deployment in overseas positions.

After being commissioned as ensigns, Navy personnel attended one of the five universities training officers for meteorological positions. This was the reverse of the Army's approach, which dictated that candidates complete their meteorological training prior to becoming commissioned as second lieutenants.[lxxxiii] In either case, meteorological education was interspersed with military drills and training. Students even managed to combine the two disciplines. Instead of counting "Hup, two, three, four" in drills, the meteorological candidates chanted "Bjerknes, Bjerknes, Bergeron, Solberg". This was in reference to the men who advanced the idea of fronts—cold, warm, and occluded. [lxxxiv]

In response to the need for weather forecasting, the armed services launched a massive effort that produced men and women trained in the science of meteorology. They learned from the most distinguished instructors in America, and brought their experience to the war effort. The shortfall in qualified applicants also provided an

opportunity for women to serve their country in a critical role. With this training, meteorologists contributed significantly to the war effort, playing a vital role in the conduct of naval operations, especially flight operations in World War II.

In the decades following World War II, fundamental shifts occurred in the structure of the Navy's meteorological staff. Originally known as the Aerology Branch, the changing needs of the Navy dictated structural changes. In 1957, the Naval Weather Service Division was formed, which elevated the status of meteorology in the navy from a branch of naval aviation, to a full divisional status. This helped reorient the weather assets from a mostly aviation focus, to a fleet-wide focus.[lxxxv]

This fleet-wide focus and the new threat of the Soviet Navy necessitated a shift in the types of information needed by military planners. Moving away from the local forecasts seen in previous case studies (especially World War II), navy meteorologists needed enough data to provide accurate products to serve a variety of needs. These needs included forecasts for large ocean areas including both meteorological and oceanographic data. This was a particularly difficult task because weather and oceanographic observations were minimal in those regions. In response to this new task, the Navy sought to extend its data gathering and information processing capabilities. These developments in data gathering and data processing will be covered in the next chapter.

With a need to provide more information to more people, the Navy merged its oceanography and meteorology branches in 1976 at the Stennis Space Center in Mississippi. This enabled the different branches to work together and combine resources to gather, process and disseminate the vital information to the forces of the US Navy.

In order to ensure the timely flow of information, the Navy maintains two production centers where supercomputers and centralized data reporting provide information to seven Fleet Support Centers throughout the world. The Fleet Support Centers provide the forecasts to naval units and other armed services within specific regions of responsibility. The Navy also maintains several detachments, which focus on METOC products within a very localized area. For example, a detachment in Naples, Italy, supports naval operations in the central Mediterranean Sea, and the Adriatic Sea.[lxxxvi]

In addition to making adjustments in the deployment of assets in response to the changing nature of METOC operations, there has also been a fundamental change in the weapons used by naval forces. The changes in ordnance necessitated changes in the types of information provided by forecasters to naval personnel. These precision guided munitions (PGM) have dramatically altered the role of METOC staff.

The weapons utilized by the Navy have changed dramatically with the advent of smart technologies. While most ordnance during World War Two could be described

as "dumb", subsequent technologies enabled manufacturers to produce PGM weapons. These PGM's have made the job of the weather forecaster more important than during previous eras of weapons development. Now, commanders in the field rely even more on the products of the METOC staff.

The Navy's arsenal before the advent of smart technology relied on guidance systems that were calibrated and set before the launch of the weapon. For example, a bomb dropped from an aircraft was released when the bombardier sighted the target through an aiming device (bomb sight) on the plane. Naval gunfire was also directed by human observers and mechanical ship-based gun sights which fed information to the gunnery officers who made settings based on this information. In either case, once the weapon was released or fired, there was no other input other than wind that would impact the direction of the explosive.

World War Two provided a key point in naval weapons development. US Navy forces experienced the pitfalls of faulty ordinance with the multitude of torpedoes that failed to detonate on target. These experiences led to the prioritization of weapons development and production. In response to this situation, the Office of Scientific Research and Development (OSRD) directly developed or funded most of the war's innovations in weaponry.[lxxxvii] Innovations from this office drastically improved the arsenal available to the Navy and the rest of America's armed forces. This same entity also provided the technological assistance in development of the first PGM's. Although

it was officially disbanded after World War II, the can-do spirit of the OSRD scientists and workers permeated those organizations that employed them. Examples of organizations that hired the thinkers of OSRD included Lockheed, Hughes, and the Naval Ordnance Test Station-which eventually became known as China Lake Naval Weapons center.

These organizations heralded the first smart weapons used by American forces. The first truly guided weapon, code-named Falcon, addressed the problem of Soviet bombers armed with nuclear weapons. With the ability for one nuclear bomb to devastate an entire metropolitan area, the US Air Force needed a weapon that could eliminate a bomber threat. In 1947, Hughes Corporation began researching the feasibility of an air to air missile, guided by radar, to neutralize the Soviet bomber threat. This was the beginning of the modern PGM.[lxxxviii] Because US forces were largely responsible for offensive air operations during the Korean conflict and exclusively responsible during the Vietnam War, the US established a lead in the development of PGM munitions.[lxxxix] These smart weapons now form the bulk of the ordnance used by America's armed forces, including the US Navy.

The weapons utilized by today's modern Navy are diverse and deadly. Although there are many different types of ordnance, groups of them share similarities that will highlight how weather affects their deployment. The sensing systems that

guide ordinance to their target include: infrared guided weapons, acoustically guided weapons, GPS guided weapons, and television guided weapons.

The Harpoon is the oldest PGM currently deployed in the Navy's arsenal. The Harpoon missile first appeared on drawing boards in 1971. McDonnell Douglas (Boeing) received approval from the Navy to begin developing an anti-ship missile with a range of 70 nm. This weapon was eventually deployed in 1977, and utilized aircraft, ships and submarines as launching platforms. The Harpoon guides itself to the target by using a variety of systems depending on the model of the missile. In a typical scenario, the Harpoon is launched along the bearing to the target. At a predetermined point, the weapon activates its seeking radar, and scans for the objective approximately 45° to each side of its course. If it cannot find a target, it executes a predetermined search pattern. If still no target is found, the missile self-destructs. Upgrades to the weapon's guidance system include an infrared imaging system, electro-optical (television) guidance, and a Global Positioning System (GPS.)[xc]

Another anti-ship smart weapon is the MK-48 torpedo. It is deployed aboard the Navy's submarine fleet, and selected surface ships involved in anti-submarine warfare. This weapon is launched on a bearing towards the target, and uses two guidance systems. Initially, a wire trails behind the torpedo, which provides direct information from sensors and computers from the firing platform. The second guidance method relies on a combination of passive and active sonar units, which guide the torpedo to its

target.[xci] Sonar guidance relies on sound, with passive units detecting the sounds of the target in the water, and active units which send out signals which bounce off the target.

The third class of weapons involves ordinance delivered on target via laser designation. The Guided Bomb Unit (GBU) 27/28, one of many laser-guided weapons, deploys from an aircraft, and seeks its target by following a laser that is provided by personnel on the ground, or by another aircraft. The personnel on the ground use specially equipped binoculars to sight the target, then "paint" the target with a laser. Aircraft use a specially mounted target designator controlled by the pilot which effectively designates the target. This does not have to be the parent aircraft of the bomb. The reflected laser is picked up by the GBU 27/28, and the bomb is released, following the reflected laser to the target.[xcii]

The new technologies utilized in PGM's have provided a large degree of flexibility to those deploying the ordinance against enemy targets. However, because of their different guidance systems, commanders must choose carefully the ordinance that will be used against targets. Unlike World War II, Korea, and the Vietnam Conflict, the military decision maker needs to know more about the environmental conditions before making a decision.

Although infrared imaging systems like those used on the Harpoon allow the weapon to be operated at night, there are environmental limitations, based on weather conditions, that must be considered. In the case of infrared detection systems, sensors

rely on Wien's Law, which states that objects of different temperature radiate energy at different wavelengths. Using this law, sensors are able to distinguish among objects of different temperatures. However, water vapor (e.g. clouds) absorbs a great deal of infrared radiation, which can wreak havoc on infrared imaging systems.[xciii] Command staff personnel must know the expected cloud cover over targets to make judgements on the appropriate weapon guidance system. The following table summarizes the limiting environmental factors of PGM's:

Figure 2: ***Environmental Variables Impacting Precision Guided Munitions***[xciv]

PGM System	Environmental Limitations
Electro-optical	Clouds, Haze, Sun Angle, Precipitation, Light Levels
Infrared	Clouds (esp. Fog), Haze, Aerosols, Sun angle, Precipitation, Light Levels
Laser	Clouds, Haze, Absolute Humidity
GPS	Wind Direction and Speed, Turbulence
Microwave (radar)	Clouds (moisture-laden), Precipitation

In most cases, if you cannot see the target, your guidance system is ineffective. For example, during the 1991 Gulf War, laser guided munitions had great difficulty operating in even sparse cloud cover. Even if the target could be seen intermittently from the air, the laser seeker on the weapon could not re-establish lock on the target after passing through clouds.[xcv] Fog, clouds, haze, humidity, wind and dust storms

(including battle induced dust) all limit the ability of sensor systems to guide their payload to target.[xcvi]

In addition to the air weapons launched from ships and aircraft, the PGM technologies utilized by the sonar units onboard torpedoes rely heavily on environmental factors. The acoustic properties of the oceans determine the performance characteristics of the sonar units. The velocity of propagation of a sound wave in the oceans depends on temperature, salinity and pressure. These variables change based on geographical location, the time of day, and depth of operations. Therefore, the characteristics of sound change from place to place and from day to day.[xcvii]

Submarine and surface ships often exploit variations in temperature, pressure and salinity when using SONAR detection. Thermoclines, or regions of large temperature change in relatively short distances can provide barriers to sound propagation. This enables submarines to hide from SONAR detection behind layers. These layers of ocean waters also prevent sound waves from traveling in straight lines. They undergo significant refraction according to Snell's Law, which states that energy passing though two different mediums (i.e. waters of different temperatures and salinity) will bend. Other factors which also affect SONAR include the topography and composition of the bottom, the surface conditions, and the ambient noise of the ocean environment. [xcviii]

In order to operate at maximum detection ranges, operators are able to calibrate their SONAR equipment. While submarines have sensors on their hull which give them instantaneous information about bathymetric conditions, surface ships and aircraft utilize expendable probes that relay essential information to detection and weapons systems. METOC also manages ASWEPS, the Antisubmarine Warfare Environmental Prediction System. This system collects information world wide and attempts to predict oceanographic conditions in order to support the operations of antisubmarine warfare units.[xcix] However, this is a very difficult task. "The ocean environment, an inhomogeneous variable and noisy medium, is often unpredictable and certainly variable both in space and time."[c]

The use of precision guided weapons has impacted the way that wars are conducted. This change in weaponry has required a change in the products generated by METOC, and this change in products requires a change in the training of the personnel tasked with providing the correct tools to military decision makers. Similar to the challenges faced in World War II, the training regimen for weather personnel has adapted to the new requirements.

METOC personnel require a high degree of training and education. Today, more than one third of the Ph.D.'s in the Navy reside in METOC positions. A high level of education is necessary down to the entry level Aerographer's Mate. Today, there is a layered training system designed for new recruits and veteran METOC personnel.

Initial training for enlisted personnel (Aerographer's Mates) commences with "A" school. This level, originally termed "observer school", seeks to make expert weather observers. Here, students start with basic weather terminology, and advance through many different levels of sophistication, including satellite analysis courses. The next level, "C" school, involves drawing conclusions from data and making forecasts. Officers attend BOATS, or Basic Oceanography Accession Training program, which seeks to combine both schools in a condensed format.[ci]

These programs have changed to meet the needs of METOC, including the proliferation of high technology. Most of the training schools are now attempting to "forecast on the glass." Forecasting on the glass refers to the computer monitor and the gradual phasing out of paper as a medium for presenting forecasts. By October 2002, the Navy hopes to have six electronic classrooms to provide METOC students with the tools needed to train the way they fight. [cii]

In addition to the recent push for more electronic teaching aids, there has been a significant push to retrain METOC personnel to address the shift to littoral environments. In 1989, COMET (Cooperative Program of Operational Meteorology, Education and Training) was established. This organization, operated by University Corporation of Atmospheric Research (UCAR), sponsored by NOAA, and funded by the National Weather Service, the Air Force Weather Agency and NMOC, seeks to improve meteorology education and training in the United States.

COMET's educational content reaches Department of Defense students in two ways. The National Weather Service conducts resident courses at sponsor institutions, or via a combination of CD-ROM and World Wide Web sites. Current curriculum includes courses dealing with COAMPS (mesoscale model), Satellite Meteorology, Short-term Forecasting (Nowcasting), and Hydrometeorology. Many of these focus on the conditions in the littoral environment.[ciii]

As the strategy of the US Navy shifted from a blue-water focus to a concentration in littoral spaces, naval operations entered a more complex meteorological and oceanographic environment. This fact coupled with the more weather sensitive smart weapons has underscored the importance of assessing and predicting environmental factors significant to naval operations. As weapons technology proliferates, and more countries have access to sophisticated weapons, any advantage that US forces can exploit becomes even more significant. One of these advantages manifests itself in the accurate forecasting by METOC personnel. This requires that personnel be well-equipped and well-trained, and the Navy has taken steps to ensure the quality of METOC personnel.

Technological innovation has been one of the most important factors driving meteorology. Advances in computers and satellites have dramatically altered the science of meteorological prediction. For example, the most powerful computers in the world are currently being used for atmospheric research due to the nature and

complexity of the Earth's environment. And, satellites tasked with providing data about terrestrial weather now provide both increased resolution and volume of data to weather researchers. Technology has dramatically altered weather prediction, and the job of METOC.

Chapter Three: How Technology has Changed Forecasting

In the middle to late twentieth century, technological innovation improved the ability of meteorologists and oceanographers to predict environmental conditions. These technological innovations included advances in numerical weather prediction, and data collection. Advances such as these allowed METOC personnel to dramatically alter the products offered to the naval community. With more good, hard data processed in a timely fashion, more accurate forecasts have disseminated efficiently throughout the Navy.

Although many technological improvements have made weather forecasting more accurate, numerical weather prediction (NWP) and the computer technology that enables the processing of NWP models remains the most significant advent in weather prediction. Numerical weather prediction generates forecasts through the use of a computer. Mathematical models of the atmosphere describe meteorological conditions and the multitude of variables impacting the weather. The models do not represent an exact state, but an approximation of conditions. By entering values into the equation (values such as temperature, dew point, wind speed, etc.), the computer predicts atmospheric conditions for a very short time interval (approximately six minutes) at certain locations called grid points.

These grid points are evenly spaced points on the map, and their relative distance (resolution) is determined by the needs of the forecast. For example, if a very

detailed forecast with closely spaced grid points is required, programmers increase computational time to provide greater resolution. However, the trade off for grid points that are spaced further apart is reduced computer time.[civ] This relationship between grid points and computational time is important in the next step of the process. By taking the results of the computations and entering them into the model again, one can see what the atmosphere might look like in twelve minutes. By repeating this process, approximations of weather conditions for twelve, thirty-six, or even forty-eight hours in the future are generated.[cv]

Numerical weather prediction was derived by Lewis Fry Richardson while working for a company that built dams. In 1922, he published a book entitled Weather Prediction by Numerical Process, in which he proposed seven equations that would completely determine the behavior of the atmosphere given its initial state.[cvi] Even though these equations could be solved, two major problems existed: data collection and speed of calculation. Enough data would have to be collected at the same time, from many different locations and many different altitudes. And, once all the numbers were collected, a quick way to execute the calculations was needed. The ability to gather and process this information in the first half of the twentieth century was limited. Richardson took six weeks to compute the weather (by hand!) for only two grid points during a six hour period (0400 to 1000 on 20 May 1910)[cvii], not a useful solution to predict weather.

World War II had a dramatic effect on the two major problems of data collection and executing calculations. Since meteorological data was needed by all branches of the Allied forces, new standardization agreements on taking and recording weather observations evolved. Ships, planes and land stations reported their meteorological observations in a standard format. For the first time, the expansion of the observational network allowed a three-dimensional data gathering and analysis.[cviii] In addition to observations, planners centralized the collection of weather data into locations called weather centrals. This meant that large amounts of data were now available for computation.

The problem of data calculation became prominent after observations became available due to the changes described above. Punch cards were used to store and calculate data, and their use soared in World War II by an order of magnitude to almost 80 million cards.[cix] However, the machines using punch cards lacked the speed to be useful in the prediction of weather.

Between 1945 and 1955, advances in the marriage of computer technology to meteorology enabled meteorologists to make daily forecasts that were rapid and more accurate. John Von Neuman and Jules Charney directed a project at Princeton University that focused on the computational problems and algorithmic design. By borrowing time on ENIAC, an Army computer located at the Aberdeen Proving Grounds in MD, new methods emerged that resulted in the viability of numerical

weather prediction. As computing power grew in the 1950's many meteorologists turned to Richardson's methods.[cx]

In the 1950's computers functioned as a research tool, but by the 1960's hundreds of new computers were marketed by at least eighty different manufacturers, all with increasing amounts of memory, disk space, and processing power.[cxi] These spectacular advances led to the widespread adoption of the computer as a meteorological instrument.[cxii] As computers advanced, METOC staff (and others) developed more sophisticated numerical weather prediction software to model the atmosphere.

Computers and the associated changes in data transmission and gathering pushed numerical weather prediction into the mainstream of meteorology. The shift to numerical weather prediction in the late 50's and early 60's was the result of four separate factors. First, the computer industry made the jump to digital communication instead of analog. Second, data transmissions could be made in the megabit scale; third, satellites could fill in large gaps in weather observations. Finally, processing power of computers increased nearly 200% in the ten years between 1955 and 1965.[cxiii] By 1961, the navy established a Fleet Numerical Weather Facility in Washington, DC, which purchased its own CDC-1604 computer to enable the processing of weather models.

As computer hardware and software progressed, new models developed to keep pace with the technological change. Between 1965 and 1980, advances in computer technology promulgated a multitude of models with varying levels of resolution.

Examples include NOGAPS, NCEP Spectral, MM5, ETA, COAMPS, ECMWF, and JMA. Of these, two have emerged in the past ten years as the primary backbone of forecasting in the Navy, and all the armed forces. Although the Army and Air Force retain weather units, the Navy provides the major modeling due to the computing power at its data processing centers.

The Navy Operational Global Atmospheric Prediction System (NOGAPS), developed by the Naval Research Laboratory in 1982, provides global weather guidance for all branches of the Department of Defense. Applications for NOGAPS include ballistic missile targeting inputs, ocean circulation models, and military aircraft routing maps. It also functions as a major weather site for the civilian community. The public domain NOGAPS web address with weather data for the entire globe receives approximately 3,000,000 hits per day. [cxiv]

Since its inception in 1982, NOGAPS resolution has increased in parallel with the processing power of the hardware running the NOGAPS software. Until 2000, a Cray supercomputer with 16 processors hosted NOGAPS, providing horizontal resolutions of approximately 150 km. In 2001, the Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, CA, successfully upgraded its computer hardware from a Cray supercomputer to a Silicon Graphics platform with a 512 processor system. This system provides more than thirty-three times the processing of the Cray system, and dramatically improved the output of the NOGAPS model. For example, instead of 150

km resolution, the NOGAPS model can attain under 50 km resolution in certain geographical locations.[cxv]

With the increased resolution, NOGAPS can provide accurate worldwide forecasts anywhere on the globe. However, the Navy has made changes in its areas of operations by shifting to littoral environments. The change to these littoral in-shore operations has necessitated forecasts with even greater resolutions. This encouraged the development of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). Like NOGAPS, COAMPS was developed by the Naval Research Laboratory, and it achieved operational status in December 1997. However, it differs significantly from NOGAPS and the other global-scale models available to forecasters. First, it is a regional mesoscale (weather phenomena less than 100km in size) model with the ability to vary the resolution by creating nested grids. Second, it can be located anywhere in the world where high resolution weather modeling is required. Finally, the model contains a high-resolution geographic database that is used in the creation of products.[cxvi]

The COAMPS model runs at FNMOC, and it can also run on a UNIX based computer in the local area. It takes standard weather inputs, including NOGAPS output, ship observations, pilot observations, and a multitude of remote sensing systems and runs them through a quality control algorithm before processing the data. [cxvii] With this data, COAMPS presents local conditions to military planners with

incredibly small resolutions. In some cases, COAMPS has been run with resolutions finer than 1 km.[cxviii]

The small resolution enables METOC personnel to make more accurate forecasts for refractivity, turbulence forecasts for aircraft, and first-order transport predictions for contaminants. This is especially important to weapons of mass destruction (WMD) planning, either defensive or offensive. As long as the approximate location of the source of the WMD is known, accurate calculation of the dispersal and effectiveness patterns is possible.[cxix]

NOGAPS and COAMPS support the ability of the METOC staff to provide accurate information. However, these models are only computer programs which rely completely on the data entered into their programs. Another important advancement involves the amount and quality of data funneled to the data processing centers tasked with executing these models.

Because of the changing role of naval forces in the post World War II era, the Navy realized it would need to generate more accurate forecasts. To support this task, there was an immediate movement to increase the data available to its staff. Specifically, the Navy sought data from locations where no observations were previously available. One of the first programs designed to accumulate remote data on weather phenomena was established in 1951.[cxx] The Navy Ice Observation program initiated flights across the Arctic regions in cooperation with Canadian researchers.

These observers not only recorded ice pack information, but provided key meteorological data on conditions in the Arctic regions. This data provided glimpses of processes occurring in the northern parts of the world, a key factor in the weather of the Atlantic and Pacific regions.[cxxi]

In 1956, the Navy's main weather office (Fleet Weather Central) and the National Weather Bureau shared Federal Building #4 in Suitland, MD. This led to close cooperation between these agencies to avoid duplication and share resources. This spirit of cooperation created the Joint Ice Center, which became the National/Naval Ice Center in 1995. Today, this organization provides data and Arctic forecasts to all government and civilian authorities in the United States and Canada.[cxxii]

After the advent of NWP, the Navy increased the amount of data coming to its weather central locations for inclusion into the forecast models. These efforts continue to the present day. One of the most recent data gathering efforts utilizes Autonomous Underwater Vehicles (AUV) deployed in critical locations. These vehicles rely on their internal programming to conduct surveys of ocean environments without being tethered or otherwise controlled. They operate using preprogrammed instructions, and artificial intelligence software located in onboard computers. Tests at the Naval Postgraduate School in Monterey, CA, have involved AUV's uploading information directly to Mine Warfare Decision Aids models, giving commanders real-time data in deciding how to neutralize the threat of mines.[cxxiii] In addition to mine warfare

operations, these vehicles collect environmental data in areas otherwise unavailable to weather personnel. Examples include gathering environmental data in advance of a SEAL team landing in a hostile littoral environment, or assessing conditions in an enemy's harbor. AUV's have a variety of sensor platforms aboard, including advanced side scan and acoustic lens sonars. In 2001, the Navy purchased fourteen AUV's, and deployed them in Fleet Battle Exercises, assessing their operational capabilities. [cxxiv]

Another recent advance in data collection involves remote buoys deployed by navy ships, aircraft and submarines. Weather collection buoys have been deployed by the Navy since 1955. On 11 October 1955, the first in a series of weather observation platforms were set adrift in the hurricane lanes north of Puerto Rico. These buoys provided continuous information on tropical storm and hurricane development.[cxxv] The buoys employed today collect data in the littoral zone, in areas where amphibious troops may land. In fleet exercises, US Navy Beachmasters deployed these littoral warfare buoys to determine oceanographic and meteorological conditions critical to the amphibious operations. These small buoys (eighteen inches diameter and sixty-three pounds) were anchored in surf zones approaching beachheads. The buoys transmitted data via ultrahigh radio frequency to a command station comprised of a laptop with a receiving antenna and a modem. The data received was automatically plugged into atmospheric and oceanographic models.[cxxvi]

These buoys logged pitch, roll, and yaw, and also had accelerometers and magnetometers measuring wave characteristics. Other information such as water depth, tides, currents, wind, and sea temperatures were also gathered. This information gathering significantly reduced the time spent by the beachmaster in gathering oceanographic and meteorological information, and provided a more accurate picture of actual beach conditions.[cxxvii]

Another important avenue of data collection has been via space-based platforms. The first pictures of the earth were taken in 1947 from a captured German V-2 rocket launched in New Mexico, and demonstrated the feasibility of weather observations from space.[cxxviii] Several confidential studies were undertaken to assess the practicality of using an earth orbiting satellite, and its contribution to meteorological analyses.[cxxix] During the mid 1950's, the Navy developed a launch vehicle known as the Vanguard, which proved very unreliable, exploding many times during its deployment. During April 1958, the Advanced Research Project Agency (ARPA) was formed to begin work on a satellite developed specifically for meteorology, TIROS I. TIROS I eventually made it into orbit under the aegis of NASA (National Aeronautics and Space Administration), and using a more reliable Army rocket. [cxxx]

TIROS (Television and Infrared Observation Satellite) demonstrated the usefulness of observing the earth from space. Cloud cover information provided by TIROS helped to locate weather systems and determined a multitude of atmospheric

motions.[cxxxi] The successful launch of TIROS I on April 1, 1960, was followed by a flood of US and USSR meteorological satellites. Between 1960 and 1970, thirty-three meteorological satellites were launched into space, and the age of satellite reconnaissance was born.[cxxxii]

The momentum gained in the 1960's carried over into the 1970's and early 1980's. Meteorological satellite programs flourished in an effective partnership between NASA and the National Oceanic and Atmospheric Administration (NOAA). The development of geo-synchronous satellites, the Nimbus program, the Global Weather Experiment and the Earth Radiation Budget Experiment are just a few examples of the size and scope of cooperation between NASA and NOAA.[cxxxiii]

During the 1980's NASA abruptly decided not to fund the development and launching of meteorological satellites. This was largely due to the high cost of developing these programs, and the rapid growth of federal decision-making and oversight. NOAA took over responsibility for the development of new weather satellites, and GEOS-8 was the first launched under the new leadership.[cxxxiv]

Using space-based platforms, meteorologists can detect a broad range of energy from low to high extremes of the electromagnetic spectrum, and a host of other important variables such as: sea temperature, ocean currents, surface winds, wave heights and distribution, surface topography, ocean color, sea levels, and ice accumulation.[cxxxv] Satellite platforms measuring this phenomenon can be divided into

two separate categories. First, geostationary vehicles orbit the equator at the same rate as the spin of the earth, and therefore stay over one geographical spot. The second type are satellites that follow the lines of longitude from pole to pole, and are termed polar-orbiting satellites. These platforms have a variety of sensors tracking both visible and invisible portions of the radiation spectrum.

The data from these orbiting platforms is utilized by Navy METOC staff in computing their models. One of the most important factors for METOC staff have been wind speeds and directions on the open ocean. Although ship-based and buoy observations provide some data, METOC lacked sufficient coverage to provide a global wind map. To construct global ocean wind conditions, METOC staff has turned to remote sensing of ocean wind patterns via space based platforms.[cxxxvi]

The satellite platforms providing this detail use a specialized radar known as SeaWinds. This type of sensor, also deployed in 1996 and 1998, uses a dish antenna with two beams which measures surface wind velocity, both speed and direction. In addition to active sensing (radar), passive sensing (radiometers) also provides another way to measure wind speeds. Using polarimetric and multi-look observations, algorithms have been derived that allow an accurate depiction of wind. The utilization of radiometers have been shown capable of determining ocean surface wind speed. The next scheduled launch of this instrument is aboard ADEOS-II, a satellite package to be launched by the Japanese Space Activities Commission. The launch is scheduled for

November 2002.[cxxxvii] The data taken from both active and passive instruments is processed by the Navy's Fleet Numerical Meteorology and Oceanography Center using the algorithm developed by Goodberlet et al.[cxxxviii]

In addition to the sources of data mentioned above, the Navy derives data from ships at sea, eight Navy military survey vessels, aircraft en route, mobile survey teams, unmanned aerial vehicles and other naval personnel stationed throughout the world. Also, several cooperative agreements with foreign nations allow the Navy access to more oceanographic and meteorological information.[cxxxix]

The availability of more data has made the products generated by METOC staff more robust and accurate. As shown, naval forces have been adept at incorporating new technologies into their areas of specialty. However, the availability of this information to on-scene commanders has been a concern. How does one get information to the right person at the right time? This concern has been a long-standing one at the Navy. As METOC produced products vital to the conduct of naval operations, the Navy sought ways to distribute information quickly to those that needed it. In 1963, the Naval Environmental Data Network (NEDN) was established allowing dissemination of weather products to naval personnel throughout the world. Upgrades to this network have allowed ever increasing volumes of information to be transmitted securely to locations worldwide.

Although the Navy has pioneered many different ways to gather data, contributions from the civilian sector have also added, or will be adding soon, to the growing sea of information. For example, in 1998, NOAA issued a report asserting that wind velocities in the lower atmosphere represent the biggest hole in observational data to make short term forecasts. Scientists based at the University of New Hampshire have devised a system employing Light Detection and Ranging (LIDAR) to measure the vertical stratification of winds in the lower atmosphere. By using a laser and measuring the scattering of the beam, wind velocities lower than one meter per second can be measured. The experiments conducted at the Bartlett, sponsored by government organizations with direct ties to the Navy including National Environmental Satellite Data and Information Service (NESDIS), will validate the feasibility of this technique to measure winds. [cxl]

SuomiNet, another project with close financial ties to the naval METOC community, utilizes the existing GPS navigational satellites to measure water vapor in the atmosphere. Researchers have already demonstrated the feasibility of measuring water vapor, and current work attempts to utilize the data in short term forecasting techniques.[cxli]

Water vapor, especially precipitable water vapor (PWV) plays a significant role in the formation and propagation of weather. However, water vapor remains one of the most poorly measured meteorological characteristics.[cxlii] A network of observing

stations, SuomiNet, provides data from stations in the United States and abroad. Plymouth State College, in Plymouth, NH, currently participates in SuomiNet guided by Professor Joseph Zabranksy and students Derek Brown and Sean Clarke. PSC is the first SuomiNet member to utilize its own data in the construction of forecasts.[cxliii] By using PWV data from SuomiNet, forecasters have positively impacted the short-range rainfall prediction and the moisture structure recovery.[cxliv]

The development of weather sensing and forecasting technologies is a partnership between government and civilian organizations. The Navy will reap the benefits of civilian research. However, civilians also benefit from the military organizations. Recently, the US Navy and The Weather Channel announced a partnership to improve the forecasting available to the public. On April 13, 2001, RADM Richard West signed a memorandum of Understanding with Vice President Ray Ban of the Weather Channel. The agreement allows The Weather Channel to access previously unavailable data to help construct more accurate forecasts. Specifically, the Navy will allow The Weather Channel to access COAMPS to help predict the weather in the littoral areas of the world. "Such collaborations will ultimately benefit the advancement of the science of weather prediction, ensuring the nation gets the greatest possible benefit from their investment in weather and oceanography."[cxlv]

Advancements in technology have dramatically improved the quality of forecasting provided by METOC staff to Navy decision makers and other Department

of Defense personnel. These improvements have included not only innovations and improvements on the part of the Navy, but contributions from the civilian sector as well. With the combined efforts of government and civilian organization, weather forecasting for everybody has been becoming more accurate.

The accuracy of these forecasts and the direction of technology poses several interesting questions for the future of METOC operations and staff. What will the impact of technology be on staffing? What are the current trends in technology and will computers replace human forecasters?

Chapter Four: The Present and Future of METOC

METOC staff has played a critical role in recent deployments of US forces. Operations in the Adriatic Sea during the Kosovo Crisis of 1998 (Operation Noble Anvil) relied heavily on the data gathered by US Navy personnel both prior and during the conflict. METOC also provided critical forecasting for cases especially dependent on weather conditions. These examples underscore the important role of METOC in the Navy. However, trends in how the Navy deploys and conducts warfighting could potentially change how METOC executes its task. The proliferation of network centric warfare may impact the distribution of human assets within the METOC community.

In the last decade, METOC staff has provided critical data as quickly as possible to the forces that rely upon it for vital information. Several proposals in the last decade have suggested improving the pace of information distribution to field units. In 1995, the NATO Supreme Allied Commander, Atlantic (SACLANT) advanced a new approach to METOC functions. Rapid Environmental Assessment (REA) is a process that fulfills the requirement to determine accurately key environmental features of the maritime littoral environment.[cxlvi] Although SACLANT is a NATO position, a large part of NATO's maritime force disposition is composed of U.S. Naval units. Consequently, this approach to METOC functions has started to permeate U.S. naval operations. At a conference in 1997, Edward Whitman presented a paper that detailed the evolving requirements for the U.S. Navy to shift to REA. According to Whitman,

the REA requires "a shift in emphasis from large scale, predictive, numerical models to 'nowcasting', quick reaction surveys….innovative processing techniques and through-the-sensor environmental measurements."[cxlvii] In order to make the shift, Whitman argues that there needs to be a fundamental change in the operational structure. "More powerful METOC fusion capabilities [need to be] deployed aboard ships and forward command facilities." In addition to greater sensor capabilities and more timely presentation of data, this includes the deployment of METOC personnel in forward areas to provide support to the decision maker.[cxlviii]

This deployment of personnel allows METOC staff to support naval operations in the complex littoral environment. This support includes oceanographic and meteorological information that enables commanders to make decisions affecting the conduct of battles. Some of these decisions include schedules, equipment deployment, and weapons selection. These decisions in regard to the "battlespace" would be nearly impossible without the support of METOC staff. This is especially true in littoral areas.

On-scene in the battle environment, METOC provides essential information in support of operations. The METOC forecaster has many different products from which to brief an on-scene commander. Synoptic forecasts and conditions ensure the safe passage of naval vessels while local and mesoscale forecasts and conditions provide key data when deploying certain weapon and sensor systems. In most cases, the naval weather forecaster is not the key decision maker for naval operations. Their job is to

translate the meteorological data into information that the on-scene commander can use to make choices.[cxlix]

When translating environmental data, METOC staff construct decision aids by repackaging forecast information into a simple form so that a decision maker can assess the threat to their forces and/or systems. In order to repackage the data, the forecaster needs to know not only the weather, but the type of weapon system, threat, or sensor-array that the decision maker has at their disposal. For example, if the directional radar on a guided missile loses effectiveness in rainy conditions, the forecaster would need to know the exact limitations of the radar and the weather conditions in the intended path of the missile.[cl]

In addition to knowing the weather and weapons systems, METOC staff provide tools that can provide alternate forms of support. The on-board Tactical Environmental Support System (TESS) can produce reports that summarize the current visibility of fleet operations to enemy radar, chaff dispersal prediction when attacked by enemy missiles and planes, radiological fallout patterns, and ballistic wind reports for naval gunfire.[cli] The REACT (Rapid Environmental Assessment Chart-Tactical) and STOIC (Special Topographic Oceanographic Intelligence Chart) are two examples of specialized METOC products used in military decision making. These products combine beach survey information, water column information, tides, wave action, and many other weather conditions essential to the safe conduct of operations.[clii]

Additionally, prediction models such as COAMPS can be run on a local computer to provide discrete weather modeling information.

To support REA, the Navy has made several recent changes in its deployment of METOC staff. Mobile Environmental Teams accompany special operations forces, including SEAL detachments, and provide local observation and product support via SIPRNET (a secure satellite based information network). For larger operations, Fleet Survey Teams deploy and provide hydrographic surveys of tactically important regions to US Navy and other Department of Defense customers.[cliii]

Some of these policies provided enormous rewards. In 1994, the survey ship USNS Littlehales conducted survey operations off the coastline of Albania. Although the survey covered a coastline of only 360 kilometers, the information gathered on tides, currents, and bottom topography proved important to the Albanian economy. All the data gathered was made available to the Albanian government, who welcomed the survey ship to their territorial waters.[cliv]

Although the Albanians received important data, the military value of the survey operation emerged in 1999. The US Navy utilized this data during Operation Noble Anvil when dealing with the crisis in former Yugoslavia. From this data, large full-scale color charts supplied to surface ship and submarine commanders allowed safe planning of routes in the Adriatic. "Without accurate information of the Albanian coastline, ships could have run around, even sunk."[clv]

In addition to providing survey data, Mobile Environmental Teams (MET) also deployed aboard ships sortied to the Adriatic. These METOC personnel, from Rota, Spain and Norfolk, VA, specialized in the changeable weather of the Adriatic. Their contributions permeated every area of Navy operations. METOC personnel provided full-spectrum weather services, including twice daily weather briefings to ship commanders, Tactical Oceanographic Summary (TOS), Tactical Atmospheric Summary (TAS), and bathythermograph observations.[clvi]

These services proved crucial to operations. The winter season in the Adriatic provided a difficult forecasting environment with the presence of localized wind phenomena such as the *Bora* and the *Sirocco*. These winds often limited operations of the NATO fleet, and accurate forecasting played a critical role. Navy operations changed three times because of the forecasted winds and their impact on navigation. Besides navigation, the winds had other consequences due to their intensity. In one instance, pilots lost contact with their home ship located only two miles away.[clvii]

Forecasters also provided support for air operations against Serb targets, sometimes more than 600 miles distant. Low visibility and ceiling over the target areas limited the effectiveness of air strikes, and weather windows had to be identified in order to deliver PGM's to their targets. Slow-moving frontal systems moved through the target region every three or four days, producing heavy cloud cover as well as

precipitation and fog. This made mission planning very difficult, and very dependent on METOC staff.[clviii]

In addition to providing information to assist offensive operations, METOC staff provided defensive support as well. The biggest threat to naval assets in the Adriatic were shore-based SSN-2 and SSN-3 Styx missile sites. Since the position of the coastal acquisition radar units were known, METOC staff generated coverage diagrams showing the effective range of these targeting systems. By taking into consideration the weather, ocean conditions, and geography, coverage diagrams provided an extra measure of security and were used by the ship commanders to plan their routes.[clix]

Another threat to ships involved the Sava-class attack submarine used by the Serbian Navy. When the conflict commenced, METOC had no data about the operational characteristics of the Serbian vessel. By teaming up with the Office of Naval Intelligence, METOC staff sourced information useful in the detection of the submarine. These parameters enabled METOC to fine-tune sonar equipment, and to produce acoustic detection ranges. This information allowed ship commanders to manage the submarine threat of the Serbian Navy.[clx]

In addition to military operations involving adversaries, METOC staff play an important role in peacetime. When the USS Cole was attacked on October 12, 2000, seventeen sailors died and the ship suffered extraordinary damage. The damage to the

ship required transportation for the *Cole* to the Litton Ingalls shipyard in Pascagoula, MS.

The Norwegian ship M/V Blue Marlin brought the *Cole* to Mississippi, and safely arrived on December 13th, 2000. From evidence in the photograph below, wind information was very crucial during the ship's journey from Yemen to the United States. METOC staff provided support for this transit, including a major first in forecasting.

Figure 3: M/V Blue Marlin carrying USS Cole[clxi]



The first in forecasting feat accomplished by the Navy involved predicting the winds and wave heights along the route of the *Blue Marlin*. Although METOC routinely uses a wave action model (WAM) to predict sea heights, the *Marlin*/*Cole* transit marked the first time METOC used a high-resolution domain from the start to finish of the route. And, it also marked the first time that data from NOGAPS and COAMPS provided the essential inputs to WAM. METOC staff created domains

approximately two days sailing time, which meant that every other day required a new forecast area.[clxii]

The winds from these forecasts were linked to WAM, which calculates wave height by taking wind speed and determining how much wave energy will change as a result of the winds. NOGAPS data filled the wind inputs in the sparse data areas (South Atlantic) and COAMPS provided data upon reaching the Caribbean Sea.[clxiii]

Accompanying the *Blue Marlin*/*Cole* transit, a METOC team deployed a localized model to provide additional input. DAMPS (Distributed Atmospheric Mesoscale Prediction System) is an automated, forward-deployed nowcast/forecast system which is run on UNIX workstations in the field. It provides on-demand tactical forecasts with resolutions from 108 km to three km. Although DAMPS had been previously utilized by the Navy, it had never been deployed on-board a moving ship. METOC provided a numerical weather prediction model for a mobile customer.[clxiv]

The employment of a moving numerical weather model represents a step in the direction of NOWCAST. NOWCAST represents the future of the Navy's METOC services. NOWCAST is a system composed of several components, including high-speed data interchange and artificial intelligence algorithms. The Office of Naval Research, the National Center for Atmospheric Research and the Lincoln Laboratory at Massachusetts Institute of Technology are developing this system. Some basic

components of NOWCAST have been proven to function in current naval operations, and the system holds significant promise for the future.

NOWCAST was conceived due to a major deficiency in weather forecasting and observations supporting naval operations. This deficiency is not a lack of METOC forecasting proficiency, but a time delay in the collection, assimilation of data, and the production of materials used by operational commanders. It is impossible under the current system to get short term forecasts (1-4 hours in the future.) Additionally, naval operations do not have the capability to share a common consistent depiction of the battlespace environment.[clxv]

A common, current, depiction of the battlespace environment is essential in the conduct of operations. By providing the same depiction to all personnel involved in the operations, more consistent decisions and situational awareness can be achieved. Currently, a wide variety of depictions provide information, depending on the geographical location of units participating in the operation, the deployment of METOC personnel and resources, and access to high-speed data links. To solve this problem of consistent timely depiction, a variety of new technologies are being exploited. These include forward deployed sensing systems, advances in data fusion technology, and the ubiquity of the internet.

By utilizing the internet as the medium of information exchange, NOWCAST systems will be able to provide near-term forecasts (1-2 hour) to military operations.

The system employs a database of environmental conditions that receives updates every five to fifteen minutes. Using COAMPS as a base line, the NOWCAST polls environmental conditions, checks for latest satellite and radar data, then publishes data via SIPRNET. Authenticated users have access to accurate forecasts for important phenomena such as microbursts and wind shear conditions.[clxvi] These authenticated users include every unit involved in an operation, providing a common view of the battlespace.

NOWCAST leverages some of the investment the US Navy has made in information technology. Other uses of this same information technology have been proposed by the educational leaders of the Navy. In the past ten years, the Navy has recognized that its adversary has changed. The Soviet Union has dissolved, and new challenges in the form of regional conflicts in littoral spaces are emerging. The enemies we face today have access to weapons of mass destruction, and some of the technologies that we utilize in our armed forces. Although we are clearly the dominant military and economic power in the world today, the Navy has chosen not to rest on its Cold War laurels. In order to counter the emerging threats, the Navy is transitioning to a new method of fighting battles, a method that first originated in the civilian sector: the networking of distributed resources. The Navy calls this approach Network Centric Warfare.

This need to disseminate information quickly has been a cornerstone in the information revolution in the civilian sector. Initially, business utilized large centralized mainframe computers dedicated to business critical tasks. The Navy followed this model in the construction of centralized data processing centers equipped with the most powerful computers available. However, starting in the 1980's business began to exploit the power found in personal computers by creating networks. These networks distributed computing power and data throughout the business. Today, handheld Personal Digital Assistants access cellular telephone networks, e-mail programs and the Internet all from a small handheld unit.

Network Centric Warfare (NCW) leverages the advances made in information technology. In many ways, NCW is a response not only to a new host of adversaries, but to the information age of the late 20th and early 21st centuries.[clxvii] Like the businesses of the 1980's, the Navy and other armed forces have centers of information that would benefit personnel if they were easily distributed and shared. NCW is an information superiority that generates increased combat power by networking sensors, decision makers and shooters to achieve a shared awareness of the battlespace. This increases the speed of command, the tempo of operations, the survivability of forces and a higher degree of synchronization.[clxviii]

Military operations have reached a point where expenditures for a weapons platform become meaningless unless the command and control processes that fire a

weapon are quick enough to react. VADM Arthur Cebrowski advanced the idea of NCW during his tenure as President of the Naval War College in Newport, RI. In an article appearing in the October 2000 Royal United Services Journal, Cebrowski notes:

> But the fact of the matter is that unless you are prepared to fix the command and control delay time issue, you are wasting your money to buy this [expensive] system. This is also an element of information superiority and should be viewed as such. Shooting is really dominated by command and control delay time. You can spend a lot of money on hypersonic weapons, and it doesn't make any difference.[clxix]

Massive amounts of money spent on weapons can be wasted if the proper information is not delivered in a timely fashion.

Network Centric Warfare directly applies to METOC because the information provided by its staff directly impacts the decisions of the battlefield commander. When trying to attain situational awareness, a decision maker must know not only locations and strengths of friendly and enemy units, but the options available for offensive or defensive responses. Any sort of decision requires complete knowledge of the meteorological and oceanographic conditions.

NCW is currently a proposal within the Naval Sea Systems Command. As a concept, it is being studied at the Naval War College, and evaluated using a simulated environment. Several war game scenarios have been executed, and the benefits of NCW are apparent.

With advances in numerical weather prediction, computer processing power, and data gathering, the future role of human METOC staff comes into question. With the rollout of NCW, information will be processed faster and more accurately than before. With more data being fed into more accurate computer models, the accuracy of predictions will increase. For example, NOGAPS accuracy has improved tremendously since 1987, a twenty percent increase in the ninety six hour forecast.[clxx] Is there a point when human interaction with weather forecasting will cease to exist?

Computers and the machines driven by them (robots) have replaced human workers in several sectors of the economy. Bank tellers and automobile assembly workers are only two of a myriad of examples. Unlike some sectors of the civilian economy, it is unlikely that METOC staff will find themselves replaced by the burgeoning technologies that improve forecasts.

One piece of evidence that supports this is the sheer number of numerical weather prediction models that are utilized by forecasters. These constructs are just models of what might happen. A model by definition does not incorporate every variable that is in the actual atmosphere. In order to simplify the calculation process, certain assumptions about the atmosphere are made, and these assumptions are not always indicative of reality. In any weather forecasting, there is an interpretation of the models, and a certain amount of human guessing to fill in the gaps left by the models.[clxxi]

METOC staff can look at the NOGAPS and COAMPS models and get an idea of what might happen down the road. The development of high and low pressure systems, and of precipitation centers may or may not occur according to factors beyond the scope of the weather models. Some of these factors include terrain data, and real time sea temperature data. Human forecasters routinely look at these outputs, then adjust them based on their experience with past forecasting.

One factor which is limiting the accuracy of models like NOGAPS and COAMPS is the nature of the atmosphere itself. The atmosphere exhibits fluid behavior, which is innately chaotic.[clxxii] E. N. Lorenz, a meteorologist at Massachusetts Institute of Technology ran a particular numerical model with almost precisely the same data inputs and received vastly different results.[clxxiii] This would suggest that no matter how many points in space are covered by instruments and no matter how much data is put into the model, the chaos theory suggests movement which is not predictable.[clxxiv]

METOC staff remain safe from replacement because of the nature of the models, and the inherent characteristics of the atmosphere. Their ability to provide more accurate forecasts to naval operations is enhanced by the use of technology. However, the elimination of human interpretation and guessing from the weather prediction process is not likely to happen.

Today's METOC staff provide increasingly accurate products via techniques under the Rapid Environmental Assessment protocol, and continue to leverage

advances in computer technology. As demonstrated in Operation Noble Anvil, METOC staff and their decision aids provided mission-critical information to the US Navy and other armed forces. In the quest for constant improvement, plans for systems such as NOWCAST will only improve the services provided by the highly trained meteorologists and oceanographers. Although technology has replaced humans in several sectors of civilian life, it is unlikely that computer technology will replace the human forecaster due to the chaotic nature of the atmosphere.

The Navy must use vigilance in deploying solutions and enhancements to the business of warfighting. By relying on innovations such as NOWCAST technologies, precision guided munitions, and computer intensive weather modeling, new and very real vulnerabilities emerge. If an adversary launches a successful attack on the Navy's information system and disrupts the flow of data, units would be without vital support. An entity launching an attack on a data distribution system does not require substantial financial resources, only knowledge of information technology. Examples of information sabotage or inadvertent network disruption permeate our society. Solar flares disrupt satellite communications, disable personal pagers, and render ATM's useless. Users routinely point out deficiencies in information systems by making unauthorized logins to the Federal Reserve or the Pentagon computer system. These events and others like them reveal the paradox of technology.

As we use more technology, we become dependent and addicted to the services they provide. Similar to the relationship between the Romans and the Germanic tribes in the first four centuries of the first millennium A.D., our society has become addicted to technology. While technological innovations make our everyday lives easier, they also create vulnerability.

The US Navy has reigned supreme on the world's oceans for approximately sixty years. Part of the Navy's success has been its ability to adapt and exploit new technologies. As METOC moves forward in providing the best possible forecasting to the Navy and other DoD customers, steps should be taken to minimize vulnerabilities inherent with the deployment of information technology and Network Centric Warfare.

Conclusion

Historically, weather has played a key role in the outcome of military operations. Although is it rarely the single greatest determiner, its part in the conduct of military operations is clear. At sea, because of the nature of the environment, forecasting plays an especially critical role. The US Navy and its METOC staff provide the best forecasting possible in the most difficult environments, including the complex littoral areas. By leveraging investments in information technology, working together with civilian partners, and providing continuous training, METOC has risen to the challenges at the end of the 20th and the beginning of the 21st centuries. These advancements have helped navy personnel provide increasingly accurate models of the environmental conditions that impact the systems and people waging war. And, although the advancements have provided exceptional tools, they do not preclude the continuing significance of the human assets in weather forecasting.

Clearly, knowledge of the weather is important. For many years, humans have tried to control nature. By simply understanding it, and learning to work within the guidelines it provides, military operations gain significant tactical advantages. In the 20th century, weather has made a transition from being a great equalizer to becoming a force multiplier. Intimate knowledge of environmental conditions and accurate predictions of their future evolution significantly enhance the fighting capability of armed forces. Prior to the massive technological changes in the 1950's and 1960's,

adversaries dealt with the same conditions, and the same abilities to forecast the weather. Any weather advantage, or "weather gauge", relied upon the unpredictable and mysterious movements of weather systems. Ghengis Khan's invasion of Japan was thwarted by a typhoon that could not be predicted by his weather diviners. However, the changes in ability to forecast, the increased weather-sensitivity of weapons systems, and the new operating environment of the littoral regions has drastically altered the importance of METOC forecasts.

In the 21st century, the Navy can use knowledge of the environmental conditions to its advantage in the selection of weapons systems, and the deployment of forces. By knowing, for example, the environmental limitations of laser-guided munitions, or the acquisition characteristics of enemy search RADARS (as in Operation Noble Anvil) significant advantages for US Navy forces are created. In these cases, weather becomes a force multiplier to the side with the most comprehensive understanding of the environment.

The superiority of US forces in weather characterization and forecasting has created a "weather gap" in relation to America's potential adversaries. The ability for Navy METOC staff to predict the weather is without peer. This weather gap is a significant advantage, especially in today's world where other gaps are closing. For example, advanced weapons are now available to anybody with the money or political capital to source them. Examples of this proliferation range from weapons of mass

destruction to shoulder-fired anti-aircraft missiles. Given the closing gaps in other areas, US forces need to find new edges in combat, and the weather is one of those advantages.

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